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ABSTRACT

The authors discuss the radiation doses absorbed by the crews of Voskhod and Voskhod-2 spacecraft. The space walk by cosmonaut Leonov exposed him to a greater dose, requiring the use of a special protective space suit. The various sources of space radiation and the protection against them are examined. Some of the experiments performed by the cosmonauts concerning space radiation are also considered.

From previously conducted investigation on artificial satellites and /1* spaceships of the Vostok type, it is known that the primary cosmic rays which are constantly present at altitudes of 300--400 km and the radiation belts of the earth do not present any danger to members of a crew during brief flights in space. This assertion was confirmed by measurements of doses of ionizing radiation made on the Kosmos-49 artificial satellite, the launch of which was carried out on the projected course of the Voskhod on the eve of its flight.

In distinction from preceding flights of spaceships of the Vostok and Voskhod types, the flight of the Voskhod-2, as far as radiation is concerned, was different in two respects: first, because of the great altitude of the orbit (the apogee was 495 km) and, second, because of the brief period of time the cosmonaut stayed outside his spaceship. It was natural to assume that these two distinguishing aspects could increase the radiation dose to which members of the crew were exposed.

Preliminary calculations of the doses for the projected orbit of the Voskhod-2 showed that the daily dose should be several times greater than during preceding flights, mainly due to the protons in the inner belt in the area of the Brazilian Anomaly but not greater than 0.1 rad/day.

The cosmonauts were to absorb the greater part of the daily dose during a period of several minutes while passing through the zone of maximum /2 intensity in the Brazilian Anomaly at an altitude of about 500 km. The total

*Numbers given in the margin indicate the pagination in the original foreign text.

time that the Voskhod-2 was to spend in the zone of heightened radiation during a day's flight was approximately 20 min. During this time the cosmonauts were to absorb about 80% of the daily dose and they were to absorb the remaining 20% from primary cosmic radiation during the course of the day. The surface dose from electrons outside the spaceship in a period of 20 min should approach one rad. Lowering it to zero required a protective layer of 100 mg/cm^2. The spacesuit of cosmonaut A. A. Leonov provided this amount of protection. In this way, the daily dose of radiation which the members of the crew of the Voskhod-2 would absorb due to the permanently present ionizing radiation on the projected orbit was not expected to exceed (calculating biological effectiveness) several tens of roentgen biological equivalents during a flight lasting several days. As is known, such a dose can have no harmful effect on the health of cosmonauts.

The main possible source of radiation damage during the flights of the Voskhod and the Voskhod-2, as in the case of other flights by spaceships of the Voskhod type, was protons from solar flares. Because of the screening effect of the earth's magnetic field, the total doses during a large flare such as those which occurred on 10 May 1959 and 12 November 1960, apparently, would not exceed several tens of rads. However, instances are known when, after some solar flares, there were observed strong disturbances of the geomagnetic field in which a particular point might be struck by particles with an energy level less than that which corresponds to the cut-off threshold under undisturbed conditions.

In Table 1 are given approximate calculated data of total doses of radiation for different thicknesses of protective envelope for the flares of 10 May 1959 and 12 Nov. 1960 in the absence of the screening effect of the geomagnetic field.

Table 1

Energy of Protons, E, MeV	Protection from air-equivalent substance, g/cm^2	12 Nov. 1960		10 May 1959	
		Integral flow, in pr/cm^2	Dose during flare, in rads	Integral flow, in pr/cm^2	Dose during flare, in rads
E > 40	1.5	3.10^9	550	$5.6.10^9$	1120
E > 80	5.0	$7.3.10^8$	90	$5.2.10^8$	70
E > 100	7.0	$4.5.10^8$	50	$1.6.10^8$	20
E > 200	24.0	$9.6.10^7$	10	1.10^7	1

As can be seen from the data presented above during the period of a flare, a cosmonaut may be exposed to ionizing radiation in doses causing impairment in ability to work and danger to life. Therefore, in organizing measures to guarantee radiation safety for the crews on spaceships greater attention is devoted to predicting solar flares which could entail radiation danger. /3

The system of measures which were taken to guarantee radiation safety on the Voskhod and the Voskhod-2 included:

predicting the radiation situation along the projected orbit;
predicting radiation danger from solar flares;
reducing the radiation dose by using a protective envelope around the spaceship;
measuring the level of radiation in the upper layers of the atmosphere with sounding balloons;
measuring the integral dose and dose intensity by an on-board radiometer;
measuring the total dose absorbed by each cosmonaut using individual dosimeters of the ILK, IKS, and IFKN types and nuclear emulsions;
the conduction of biological dosimetry of cosmic radiation;
lowering the effectiveness of biological action of ionizing radiation in emergency situations by using pharmaco-chemical preparations.

As is known, this system of measures to guarantee safety was used successfully in all flights carried out with a man on board (refs. 2-4).

For calculating the effect of possible soft radiation (electrons) A. A. Leonov and P. I. Belyayev, during the time they were outside the spaceship, were equipped with identical sets of individual dosimeters which were able to function under conditions of deep vacuum. The dosimeters were worn near the chest area under the spacesuit and in the outer hip pocket.

During the preflight and flight periods of the Voskhod and Voskhod-2, according to data from optical, magnetic, and radio observations, the sun was in a state of minimum activity. However, on 9 October 1964 (three days prior to the flight of the Voskhod) at 8:30 at an altitude of 22 km, when measurements were being made of the intensity of radiation in the upper layers of the atmosphere, a brief increase in the radiation background by a factor of 23 (4680 particles/cm^2/min) was registered over the normal rate (210 particles/cm^2/min). In approximately two hours, the intensity of the radiation again returned to normal. The cause for the increase in intensity of radiation was not determined.

The mean values of the doses absorbed by members of the crews of the Voskhod and Voskhod-2, according to data from measurements made with the individual and on-board dosimeters, are presented in Table 2.

Table 2

Total Doses of Raidation Absorbed by Members of the Crews of the Voskhod and Voskhod-2 in Tissue mrads.

Name of Spaceship	Individual Dosimeters		On-Board Dosimeter, R-ZAM	
	Mean Dose per Flight, in mrad	Mean Strength of Dose, in mrad/day	Dose during Flight, in mrad	Strength of Dose, in mrad/day
Voskhod	30±5	29±3	27±1	26±1
Voskhod-2	70±5	65±3	65±1	60±1

As can be seen from Table 2, the doses absorbed by the cosmonauts was about 30 and 65 mrad for members of the crews of the Voskhod and Voskhod-2, /4 respectively. The apprehension that the dose absorbed by a cosmonaut who exited from the Voskhod-2 would be greater due to soft radiation of electrons was found to be unjustified.

An analysis made of the composition of radiation for the Voskhod-2 (18-19 March 1965) using nuclear emulsions showed that the flow of particles with linear losses of energy corresponding to overall losses of energy at the end of a trip of alpha particles, boron, oxygen, and argon came, respectively, to 200, 30, 15, and 3 particles/day/cm^2 of emulsion 200 μ thick. The data for oxygen and argon are not sufficiently precise because of the small exposure.

The mean value of the intensity of tissue dose on the Voskhod was two times greater and on the Voskhod-2 four times greater than during the last flights of the Vostok. Such growth in the doses of cosmic radiation can be explained principally by the change in the altitude of flight, as a result of which the total dose increased due to the protons in the inner belt in the area around the Brazilian Anomaly, and also by a certain increase in the intensity of primary cosmic radiation characteristic of the period when the sun is quiet. The radiation dose absorbed by members of the crew of the Voskhod and Voskhod-2, allowing for the coefficient of relative biological effectiveness, did not exceed several tens of biological roentgen equivalents. It is altogether obvious that such a dose cannot have a harmful effect on the health of cosmonauts.

In addition to the dosimetric apparatus on board the ships, there were various biological specimens such as air-dried seeds of wheat, pine, beans, and carrots; microspore of Tradescantia paludosa; a lysogenic culture E. coli K-12 (λ); and pomace flies which were used primarily for a biological indication of ionizing radiation. The specimens were kept in special containers on board the ships as well as in the hip pockets of the spacesuit worn by A. Leonov (pine and wheat seeds, lysogenic bacteria).

The biological effectiveness of cosmic radiation acting together with /5 other flight factors was evaluated using cytogenetic, genetic, physiological, and microbiological methods of investigation.

An analysis of the material obtained showed that under the influence of flight factors, including cosmic radiation, in the hereditary structure of several specimens, such as the microspore of spiderwort and the pomace flies, there occurred changes in the quantitative and qualitative relationships similar to the effects registered on the flights of the Voskhod-2, Voskhod-3, and the Voskhod-6. Thus, in comparison with the control specimens, there was found an increase in the frequency of non-divarication of chromosomes and an increase in the frequency of dominant lethals among the pomace flies, disruption of the mechanism of mitosis in the microspore of the spiderwort, etc. At the same time the recorded changes, as far as quantity is concerned, proved to be insignificant as in the tests conducted on the Vostok.

At the same time the effects characteristic of radiation influence and other factors on the lysogenic bacteria and seeds of the higher plants, specimens of which were kept on the spaceships as well as exposed in outer space, were not manifest (ref. 5).

Of particular interest are the results obtained in an experiment with microspore of spiderwort conducted with the participation of B. B. Yegorov. The data obtained gave evidence of the fact that the phases of mitosis in microspore of spiderwort have varying sensitivity to the effects of factors encountered in space flight. Moreover, they confirmed the hypothesis expressed previously to the effect that the cause for the disruption of the mechanism of mitosis could be the state of weightlessness and that the rearrangements of chromosomes are caused primarily by the effects of a complex of factors associated with lift and launch of the spaceship (ref. 6).

In this way, the results of biological experiments agree quite satisfactorily, as was the case with flights of the Vostok spaceships, with data concerning the dose of cosmic radiation as determined by using various physical dosimeters. Clinical observation of the health of members of the crews of the Voskhod and Voskhod-2 conducted regularly after the flights also confirm convincingly the lack of any harmful effects from cosmic radiation.

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